Low-Cost Polymer Based Solar Domestic Hot Water Systems

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ABSTRACT

Research at the University of Minnesota focuses on design, material and thermal performance issues that offer opportunities to improve performance, durability and/or to reduce the cost of polymer based solar domestic hot water (SDHW) systems. Results demonstrate 1) an internal baffle provides a modest improvement in the rate at which stored heat is extracted from a tank with an immersed heat exchanger, 2) for polyolefins (a low cost commodity polymer) the mechanical performance and lifetime will depend on the rate at which antioxidants are lost to the surrounding potable water and 3) scale formation on polymer tubes is 30% less than that on copper tubes after 2 months exposure to flowing tap water.

1. Objectives

The University of Minnesota effort supports two industry teams who are developing polymer based SDHW systems. Our foci are material and thermal performance issues related to water storage tanks and heat exchangers. The project objectives are:

1) to seek methods of improving the thermal performance of an indirect water storage tank in which stored heat is extracted via an immersed heat exchanger,
2) to assess material durability of candidate polymers exposed to potable water, and
3) to compare scaling (the growth of calcium carbonate) on polymer and metal surfaces.

2. Technical Approach

2.1 Thermal performance

Polymer water storage tanks under consideration are unpressurized and use an immersed heat exchanger to discharge (and/or charge) the stored energy. The transient thermal/fluid processes in a vertical tank were analyzed using boundary layer theory to determine if an internal baffle could increase the rate of energy discharge.[1] A sketch of the baffle design selected for modeling and prototyping is shown in Fig. 1. The cylindrical baffle creates an annular space in which a coiled heat exchanger tube is placed. The flow and temperature fields in the tank were modeled by treating the heat exchanger as a porous medium within the storage fluid.[2,3] The transient temperature distribution, heat exchanger inlet and outlet temperatures, and overall heat transfer of a tank with and without a baffle were measured and compared.[4]

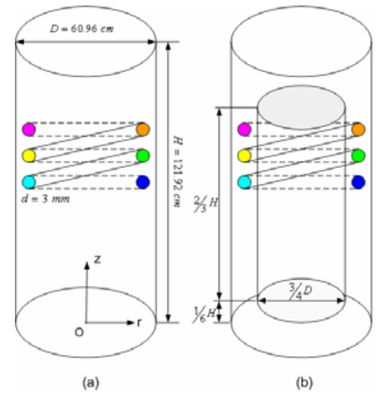

Fig. 1. Indirect storage tank with an immersed heat exchanger; (a) without baffle, and (b) with baffle.

2.2 Durability of polymer heat exchange materials

The successful use of polymer components requires a method of predicting material degradation in water. Degradation from oxidation can be delayed through the use of antioxidant additives. A model of the antioxidant loss from polymer tubes was developed and used to predict life of polyolefin tubes in an immersed heat exchanger.[5,6] The model considers the coupled diffusion equations for the antioxidant and reactant species in the polymer.

2.3 Scaling of polymeric materials

All heat exchangers operated in an open loop with water supersaturated with respect to calcium carbonate or other inverse soluble salts are prone to scale. Scaling of polymer tubes was measured on tubes exposed to flowing water supersaturated with respect to calcium carbonate. Prior experiments were carried out under accelerated scaling conditions in distilled water. This year experiments were conducted with more realistic conditions in tap water.[7] The scaling behavior of polymer tubes (polypropylene, polypropylene random copolymer, and crosslinked polyethylene) is compared with that of copper.

3. Results and Accomplishments

3.1 Thermal characterization

The CFD results predict a simple cylindrical baffle will increase the rate of discharge by 10%. Experimental data shown in Fig. 2 confirm this result. The fraction of the stored energy discharged is plotted versus time. The rate of energy discharge is consistently greater with the baffle. During the first 30 minutes of discharge, 24.3% of the stored energy is discharged with a baffle compared to 19.7% in the tank with no baffle.

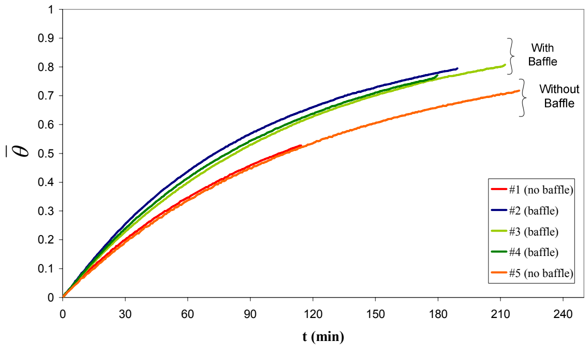

Fig. 2. Comparison of fractional energy discharge with and without baffle.

3.2 Durability of polymer heat exchange materials

The rate of antioxidant loss is controlled by diffusion through the polymer. The diffusion time scale is dictated by the tube wall thickness. The fraction of the initial amount of antioxidant remaining in tubes with wall thickness of 1 or 2 mm, both with diameter to thickness ratio of 18, is compared in Fig. 3. The time to deplete 90% of the antioxidant is on the order of 10^3 for the thinner tube and 10^4 hours for the thicker tube.

3.3 Scaling of polymeric materials

In the accelerated study, scale was quantified after 2.5, 5 and 7.5 hours of exposure. The mass of scale on all tubes increased with time; the scale morphology consisted of calcium carbonate particles and 1-10 μm particle clusters. The scaling rate was the same order of magnitude on polymer and copper tubes. Under more realistic conditions (lower hardness tap water), data were taken after 3, 4 and 6 weeks of exposure. In this case, the scaling rate was much lower. The scale consisted of 100 nm particles and included calcium phosphate as well as calcium carbonate. The mass of scale on copper tubes was 30% higher than that on PP tubes.

4. Conclusions

Use of polymer heat exchangers for solar hot water storage systems poses thermal and material challenges but holds promise for lower cost systems. When energy is discharged in an unpressurized storage tank via an immersed coiled tube heat exchanger, the use of a cylindrical baffle boosts the rate of energy delivery by 10%. Durability and lifetime of polymer tubes will depend on antioxidant depletion rate. The depletion rate for conditions expected for immersed heat exchangers is dictated by the tube wall thickness. Measurement of scaling in polymer tubes under realistic conditions shows the initial scaling rate for polymers is less than that for copper.

Future research will i) explore the use of alternative methods to improve thermal performance and to extend solar heating systems for space conditioning,

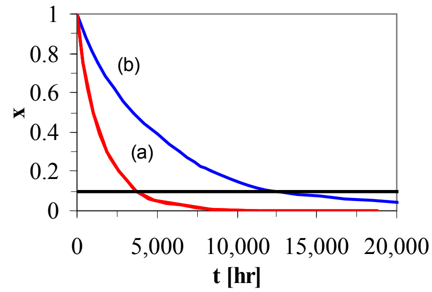

Fig. 3. Fraction of antioxidant in the tube versus time for wall thickness of (a) 1 and (b) 2 mm. T = 333 K.

ii) validate our models of antioxidant loss and its relationship to mechanical durability, and iii) assess scale adhesion on polymers.

Acknowledgments

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